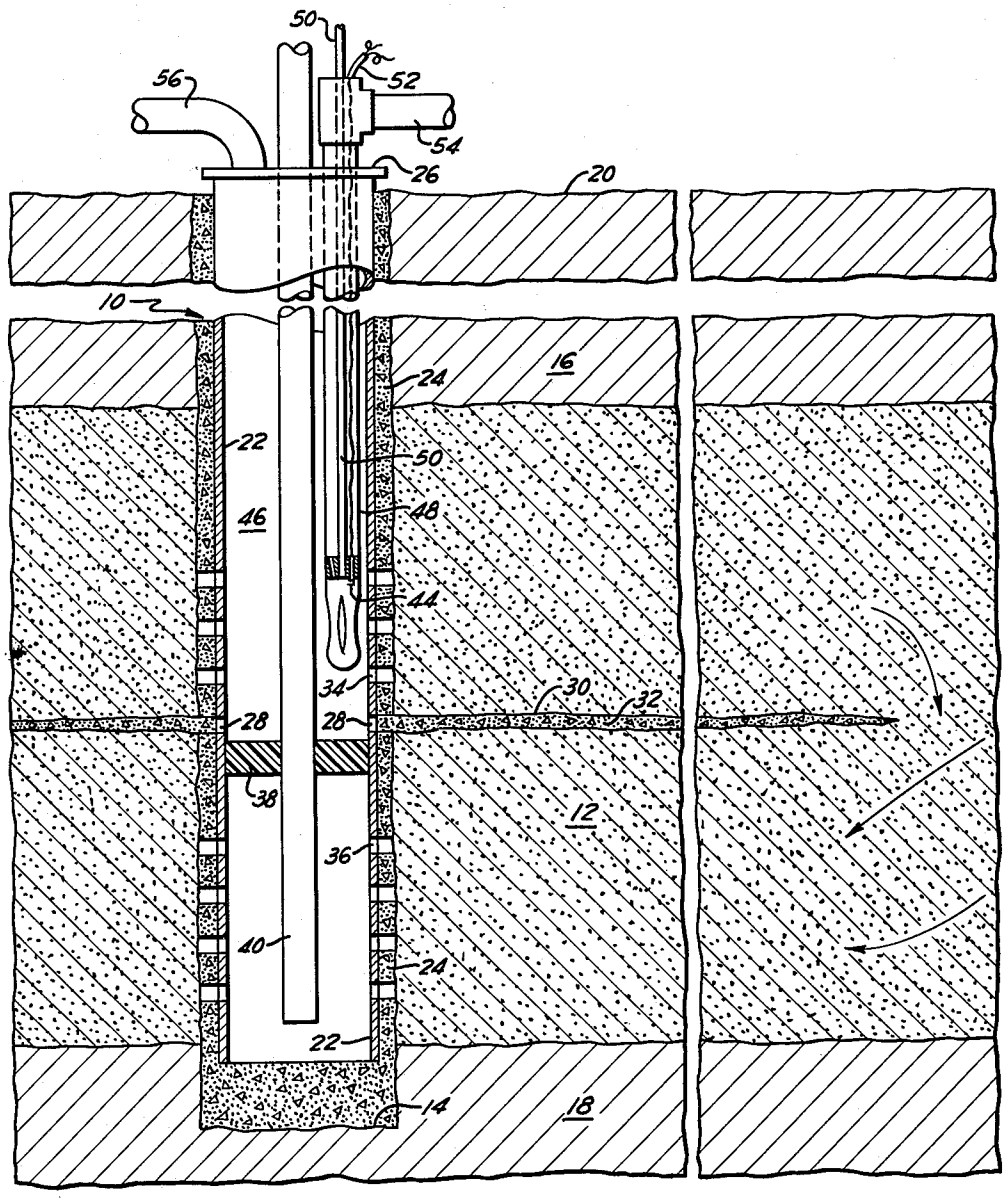
Oct. 17, 1961 J. H. HENDERSON ET AL 3,004,600

SINGLE WELL IN-SITU COMBUSTION PROCESS FOR PRODUCTION OF OIL

Filed June 17, 1957



INVENTORS
JAMES H. HENDERSON
ALFRED SCHILD
MALCOLM R. J. WYLLIE

BY

THEIR ATTORNEY

United States Patent Office 3,004,600
Patented Oct. 17, 1961

3,004,600

SINGLE WELL IN-SITU COMBUSTION PROCESS FOR PRODUCTION OF OIL

James H. Henderson, Gibsonia, Alfred Schild, Pittsburgh, and Malcolm R. J. Wyllie, Allison Park, Pa., assignors to Gulf Research & Development Company, Pittsburgh, Pa., a corporation of Delaware

Filed June 17, 1957, Ser. No. 665,990
6 Claims. (Cl. 166—39)

This invention relates to a process for the recovery of oil from oil bearing formations by an in-situ combustion process and more particularly to an in-situ combustion process using a single well. This invention is especially useful in the secondary recovery of a highly viscous oil by an in-situ combustion process.

The primary recovery of oil from oil bearing formations, hereinafter referred to as pay zones, utilizes the natural pressure on the pay zone to force the oil through the permeable formation of the pay zone to the well. The pressure on the pay zone may be sufficient to deliver oil to the well head, or, if the pressure is not adequate, artificial lift is used to raise oil in the borehole to the surface. Usually only a small fraction of the oil present in the pay zone can be recovered by primary recovery processes.

Secondary recovery methods in which the pay zone is repressured to move the oil through the formation are frequently used to increase the amount of oil recovered. The repressuring can be accomplished by the injection of gas into the upper part of the formation or water into the lower part to provide the pressure necessary to move the oil through the formation. In another secondary recovery process referred to as an in-situ-combustion process, oil in the formation is ignited and an oxygen-containing gas is pumped into the formation at an input well to continue the burning. The oxygen-containing gas and products of combustion force oil through the pay zone to an adjacent production well from which the oil is withdrawn.

In the usual in-situ combustion process in which an oxygen-containing gas is injected at an input well to burn a portion of the oil and supply energy aiding in moving the oil to an adjacent production well, the oil and the formation well in advance of the combustion front are relatively cold. It is that oil which causes the principal resistance to flow through the formation as it flows through the reduced area of the pay zone immediately surrounding the production well. The resistance of the cold oil to flow is especially severe if the oil is a heavy, highly viscous crude oil. It is frequently necessary to build the pressure on the reservoir to very high levels to obtain a significant increase in the rate of production, which results in a long time before any benefits are obtained from the in-situ combustion. The resistance to flow through the formation to the production well is further increased by condensation of water formed during the combustion which partially hydrates clays that may be present in the formation and causes the clays to swell and further plug minute passages in the formation.

This invention resides in an in-situ combustion process employing a single well in which the pay zone is fractured near its center and cement is squeezed into the fracture to form a barrier extending radially from the well through the pay zone. The well casing is then perforated above and below the fracture and the resulting upper and lower perforations separated with a packer. Oil is ignited in one of the sections of the pay zone, for example in the upper section above the cement barrier. Air is injected into that section to continue the burning and oil is produced from the other section of the formation and lifted to the well head. Oil moved by

formation pressure into the pay zone below the barrier is heated and diluted to reduce its resistance to flow inwardly to the well. Periodically the direction of flow in the two zones of the formation is reversed by alternating the sections into which the oxygen-containing gas is injected and from which the oil is produced.

The single figure of the drawing is a diagrammatic illustration, principally in vertical section, of a well adapted to use the secondary recovery process of this invention.

Referring to the drawing, a borehole indicated generally by reference numeral **10** of a well is drilled completely through a pay zone **12** to a total depth **14**. The pay zone **12** lies between an inpervious cap rock **16** and a base rock **18**. The ground surface is designated by reference numeral **20**. Casing **22** is set substantially to total depth in the borehole **10** and is cemented completely through the pay zone **12** as indicated by reference numeral **24**. In the apparatus illustrated in the drawing, the cement **24** extends to the surface **20** of the ground. The upper end of the casing **22** is closed by suitable well head connections, indicated diagrammatically by a cap **26**.

After the cement has set, the casing **22** is perforated at **28** at the middle of the pay zone **12**. The formation is then fractured at **30** through the perforations **28** by conventional fracturing techniques such as the technique described in United States Letters Patent No. 2,642,142 of J. B. Clark issued June 16, 1953. A propping agent, for example sand, is used to hold the fracture open after pressure has been released. The fracture **30** can be made to extend for any desired distance. Ordinarily fracture **30** will extend for a distance of at least 50 feet and preferably from 100 to 200 feet. Larger fractures, for example fractures having a radius of 600 feet or more can be used. The extent of the fracture will depend largely on the characteristics of the pay zone and factors affecting the fracturing operation rather than this invention. An impermeable heat resistant cement such as a high-alumina cement is squeezed into fracture **30** to form a barrier indicated by reference numeral **32** extending radially from the well at about the mid point of the pay zone. A suitable cement is one manufactured by LaFarge Aluminous Cement Company, London, England, identified by the name "Ciment Fondu."

The barrier **32** divides the pay zone into an upper section above the level of the barrier and a lower section below the barrier. The upper and lower sections are cylindrical in shape, having a radius equal to the radius of the barrier and heights of approximately one-half the thickness of the pay zone in the preferred arrangement in which the barrier is at the approximate center of the pay zone. Clearly the barrier can be at a different level in the pay zone as long as radial flow above and below the barrier can be obtained.

After the cement in barrier **32** has set, the casing **22** and cement **24** are perforated at **34** above the barrier **32** and at **36** below the barrier **32**. A heat resistant packer **38** is set in the casing between the perforations **34** and **36** and a tubing **40** is run through the packer for delivery of production from the well. Tubing **40** will ordinarily contain suitable lifting equipment, not shown, to raise the oil to the well head. An igniter, illustrated diagrammatically and indicated by reference numeral **44** is run into the annular space **46** between the tubing **40** and the casing **22** to a position above packer **38**, preferably adjacent perforations **34**. An igniter of the type described in United States Letters Patent No. 2,668,592 of J. J. Piros et al. can be used.

Igniter **44** is supported at the lower end of a pipe **48** and is connected with a fuel feed line **50** extending downwardly through pipe **48** from the well head. An electric lead line **52** also is run down through the pipe **48** and connected to a suitable spark plug in the igniter

to supply a spark for ignition of the mixture. An oxygen-containing gas, which may be air, air enriched with oxygen, or air diluted with an inert gas such as a flue gas, is supplied to the upper end of pipe 48 through a supply line 54. Additional oxygen-containing gas may be supplied, if required, through the annulus 46 by means of a supply line 56.

In the operation of the process of this invention the section of the pay zone above the barrier 32 is heated to a temperature at which oil present therein will be ignited on contact with oxygen-containing gas injected into that section. In the embodiment illustrated in the drawing, the ignition is accomplished by introducing a fuel such as natural gas or lease gas through gas feed line 50. An oxygen-containing gas, which ordinarily will be air, is supplied through supply line 54 and pipe 48. The fuel and oxygen-containing gas are ignited by igniter 44 and the fuel burned to heat the formation above barrier 32. After a heating period long enough to ignite the oil in the upper section of the formation the flow of fuel is stopped. The flow of oxygen-containing gas is continued to maintain the combustion in the pay zone. Ordinarily it is desirable to increase the rate of injection of the oxygen-containing gas gradually as the area of the combustion front increases. The rate of injection, which will depend upon a number of factors such as the total thickness of the oil bearing formation, its permeability, the characteristics of the oil, and the radius of the barrier, will generally exceed 100,000 standard cubic feet per day and may be as high as 1,000,000 or more standard cubic feet per day.

The combustion of oil in the upper section of the formation heats that formation to a temperature sufficiently high to irreversibly dehydrate and thereby stabilize clay that may be present therein and cleans the formation to increase its permeability. The high temperature in the upper section of the formation also results in the transfer of heat through the barrier 32 to heat the cylinder of the pay zone below the barrier. The hot products of combustion heat oil radially outward from the combustion front causing some cracking of the oil to lighter, more volatile and less viscous components. The increased pressure in the upper section of the pay zone resulting from the injection of the oxygen-containing gas pushes oil in the upper section radially outward past the outer edge of the barrier 32.

The pressure of the pay zone moves oil from the formation radially into the lower cylinder below the barrier 32. The large area of the outer surface of the cylinder of the lower section below the barrier allows substantial total flow of fluids from the pay zone into the lower section in spite of the low velocity of the fluids. Although the pressure on the pay zone may be low, the low velocity of the oil causes a very low pressure drop from the pay zone to the lower section of the pay zone under the barrier 32.

Once oil from the formation is in the lower section of the pay zone under the barrier 32, it is heated by admixture with hot oil and combustion products from the upper section of the pay zone and by heat transferred through the barrier. The increased temperature of the oil and its admixture with cracked oil and combustion products from the upper section sharply reduces the viscosity of the oil and its resistance to flow through the lower section to the well.

The injection of the oxygen-containing gas into the upper section of the formation is continued until the ratio of injected gas to oil produced in the product lifted through tubing 40 becomes excessive. The length of the time which burning is continued in one direction will depend on several factors such as the thickness of formation, the vertical permeability, and the radius of the barrier 32. In some instances the well may be furnished with igniters and tubing to allow reversal of the direction of burning by merely changing well head connections in which event the period of burning in one direction can be reduced. The minimum time of burning in one direction is about 15 days. In most instances, however, it will be desirable to continue burning in one direction, for example in the upper section of the formation, for a period of two to six months or longer, before changing the connections in the well to allow burning in the lower section.

When the injected gas to oil produced ratio becomes excessive, the injection of oxygen-containing gas is stopped, the tubing 40 is pulled and the igniter 44 and pipe 48 are run to a level below packer 38. A tubing corresponding to tubing 40 for the lift of oil from the well is then run into a level above the packer 38. Thereafter the procedure for ignition of the formation in the section adjacent the igniter is repeated and oil is withdrawn from the well through the upper section of the formation. After the initial burning, the process of this invention has the advantage of producing the oil through a clean section of the formation in which any clays that may be present have been stabilized against the action of water in the products of combustion or from the formation, thereby further reducing the resistance to flow inwardly to the well. Combustion in the lower section is continued until the injected gas-produced oil ratio becomes excessive, after which the operations in the upper and lower sections are again reversed. The reversal can be repeated periodically until the formation is substantially depleted. At each reversal, ignition is facilitated by oil adjacent the well in the section in which combustion is to take place.

Although this invention has been described with the initial in-situ combustion occurring in the upper section of the formation the invention is not so limited and an initial combustion can take place in either the upper or lower section. In the event that the initial combustion is in the lower section, combustion in the lower section is continued while oil is withdrawn through the upper section, until the injected gas-oil produced ratio becomes excessive, and then the operations in the two sections are reversed.

In a specific example of this invention a seven inch casing is set through a pay zone 35 feet thick having its bottom at a total depth of 3,760 feet. The casing is perforated at a depth of 3,742 feet and the pay zone fractured through the perforations for a radius of 150 feet. A heat resistant high alumina cement is squeezed into the fracture to form an impermeable barrier having a radius of approximately 150 feet.

The casing is perforated through the zone above and below the barrier. A heat resistant packer is set in the well between the perforations above and below the barrier and the well completed for injection and ignition of a mixture of a fuel and an oxygen-containing gas in the upper section of the pay zone.

A lease gas and air are injected into the well at a rate of 200 standard cubic feet of the lease gas per hour and a rate of 4,000 standard cubic feet of air per hour, respectively. The mixture is ignited and the lease gas injection is continued for three days after which the lease gas injection is stopped. The rate of injection of the air is gradually increased to 500,000 standard cubic feet per hour and that rate is continued for a period of two months. During the two month period oil delivered from the formation into the casing below the packer is lifted to the well head. At the end of the two month period the injection of air is stopped. The well fittings are reversed and the procedure repeated with the exception that the combustion occurs in the lower section of the formation.

In the in-situ combustion process of this invention after an initial period of burning the oil flowing radially inward to the well has been heated and mixed with less viscous cracked products and carbon dioxide. Consequently, the viscosity of the oil flowing through the pay zone imme-

diately surrounding the well, where the velocity and resistance to flow are greatest, is sharply reduced. Because of the large area for flow from the formation into the portion of the pay zone directly above or below the barrier, depending on the direction of flow, and the resultant low velocities, a low pressure in the pay zone will cause a large total flow of oil to a position where the in-situ combustion process of this invention will sweep the oil to the well. When the combustion front reaches the edge of the barrier, some of the oil moving into the flow pattern from the formation outside of the barrier is burned and thereby heats directly other oil moving inwardly to the well.

We claim:

1. An in-situ combustion process utilizing a single well for the production of oil from a pay zone comprising forming a fracture in the pay zone, pumping a liquid into the fracture to extend the fracture substantially radially from the well at least about 50 feet into the pay zone, said fracture being positioned in the central portion of the pay zone, squeezing cement into the fracture and allowing it to set to form a thin impermeable barrier extending from the well and dividing the pay zone into an upper and lower section, setting a packer in the well adjacent the barrier to divide the well into an upper zone above the packer and a lower zone below the packer, running tubing into the well and through the packer to provide a conduit from the well head to the lower zone, injecting an oxygen-containing gas down the well and into one of the sections of the pay zone, igniting and burning oil in that section into which the oxygen-containing gas is injected to increase the temperature therein and displace oil toward the other section of the pay zone, withdrawing oil from the other section of the pay zone into the well and lifting it to the well head, stopping the injection of oxygen-containing gas into said one section, injecting oxygen-containing gas into said other section, igniting oil in said other section, and withdrawing oil from the section of the pay zone in which the burning initially occurred to cause alternate burning and withdrawal of oil in the sections.

2. An in-situ combustion process for the production of oil from a pay zone utilizing a single well comprising forming a thin impermeable solid barrier extending substantially horizontally from the well into the pay zone for a radial distance of at least about 50 feet in the central portion of said pay zone to divide the pay zone into an upper and lower section, setting a packer in the well adjacent the barrier to divide the borehole of the well into an upper zone above the packer and a lower zone below the packer, running tubing into the well and through the packer to provide a conduit from the well head opening into the lower zone, initially injecting an oxygen-containing gas down the well and into one of the upper section and the lower section, igniting oil in the section into which the oxygen-containing gas is injected, continuing the injection of the oxygen-containing gas down the well and into the section to continue burning oil in the section to increase the temperature therein to a range at which clays are irreversibly dehydrated and displace oil through the pay zone toward the other section, simultaneously with the burning withdrawing oil from the other section of the pay zone into the well and lifting it to the well head, stopping the injection of oxygen-containing gas into the section into which the oxygen-containing gas was initially injected when the injected gas-produced oil ratio becomes excessive, then injecting oxygen-containing gas down the well and into said other section, igniting oil in said other section, continuing the injection of oxygen-containing gas down the well and into said other section to burn oil in the pay zone and displace oil from said other section into the section of the pay zone into which the oxygen-containing gas was initially injected, and withdrawing oil from the section of the pay zone into which the oxygen-containing gas was initially injected into the well for delivery to the well head.

3. A process as set forth in claim 2 in which the radius of the impermeable barrier is about 100 to 600 feet.

4. A process as set forth in claim 2 in which the injection of oxygen-containing gas in the section of the pay zone into which the oxygen-containing gas is initially injected is continued for a period of 2 to 6 months before stopping the injection of the oxygen-containing gas into that section and injecting the oxygen-containing gas into, and igniting oil in, the other section.

5. In an in-situ combustion process for recovering oil from a pay zone through a single well, said well having a thin impermeable barrier extending substantially horizontally radially outward therefrom into the pay zone for a distance of at least about 50 feet to divide the pay zone into an upper section and a lower section, a packer set in the borehole of the well adjacent the barrier to divide the well into an upper zone above the packer and a lower zone below the packer, and tubing extending down the well and through the packer to provide a conduit from the well head to the lower zone, the improvement comprising initially injecting an oxygen-containing gas down the well and into one section of the pay zone, initially igniting oil in the section of the pay zone into which the oxygen-containing gas is initially injected, continuing the injection of an oxygen-containing gas down the well and into the section of the pay zone into which the oxygen-containing gas is initially injected to maintain combustion of oil in the pay zone to increase the temperature of the pay zone and displace oil through the pay zone towards the other section, simultaneously with the combustion in one section delivering oil through the other section to the well and lifting the oil to the well head, stopping the injection of the oxygen-containing gas into the section into which the gas was initially injected, injecting an oxygen-containing gas down the well and into said other section, igniting oil in said other section, continuing the injection of oxygen-containing gas down the well and into said other section to burn oil in the pay zone and displace oil from the pay zone to the section into which the oxygen-containing gas was initially injected, and delivering oil through the section in which the oxygen-containing gas was initially injected for lifting to the well head.

6. A method of producing oil from a single well by an in-situ combustion process comprising drilling a well through a pay zone, setting casing in the well through the pay zone, cementing the casing in place through the pay zone, perforating the casing near the central portion of the pay zone, forming a substantially horizontal fracture in the pay zone through the perforations near the central portion of the pay zone, pumping a liquid into the fracture to extend the fracture from the well into the pay zone for a radial distance of at least about 50 feet, squeezing a heat resistant cement into the fracture and allowing the cement to set to form a thin barrier extending for a distance of at least about 50 feet from the well into the pay zone to divide the pay zone into an upper section and a lower section, perforating the casing in the pay zone above and below the barrier, setting packing means in the well to isolate the perforations above the barrier from the perforations below the barrier and divide the well into an upper zone above the packing means and a lower zone below the packing means, running tubing down the well and through the packing means to provide a conduit from the well head to the lower zone, initially injecting an oxygen-containing gas down the well and through the perforations into one of the upper section and the lower section, igniting oil in the formation in the section into which the oxygen-containing gas is initially injected, continuing the injection of the oxygen-containing gas down the well and into the section in which the oil is ignited to burn oil in the formation to increase the temperature therein and displace oil to the other section, delivering oil from the pay zone through

said other section into the well and lifting it to the well head, continuing the injection of an oxygen-containing gas down the well and into the section in which the ignition occurred to maintain burning in that section to heat the pay zone to a temperature at which clays in the pay zone are irreversibly dehydrated, discontinuing the injection of oxygen-containing gas into the section into which the oxygen-containing gas is initially injected upon increase of the injected gas-produced oil ratio to excessive ranges, injecting an oxygen-containing gas down the well and into said other section, igniting oil in said other section, continuing the injection of an oxygen-containing gas down the well and into said other section to maintain burning, and delivering oil through the section in which ignition initially occurred into the well for delivery to the well head.

References Cited in the file of this patent

UNITED STATES PATENTS

2,368,424	Reistle	Jan. 30, 1945
2,412,765	Buddrus et al.	Dec. 17, 1946
2,668,592	Piros	Feb. 9, 1954
2,754,911	Spearow	July 17, 1956
2,767,792	Spearow	Oct. 23, 1956
2,796,935	Bond	June 25, 1957
2,818,118	Dixon	Dec. 31, 1957
2,819,761	Papham	Jan. 14, 1958
2,874,777	Tadema	Feb. 24, 1959
2,958,380	Schild	Nov. 1, 1960